PHOTOVOLTAICS

FOR THE STATES:

Lessons Learned and Project Summaries

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This report reviews a variety of stand-alone and grid-tied photovoltaic systems—together worth more than $2 million—installed in projects during the last half of this decade with assistance from Sandia's Photovoltaic Systems Assistance Center, which is sponsored by the U.S. Department of Energy. Sandia was helped by the Interstate Renewable Energy Council, the Photovoltaics for Utilities program, and by partnerships with organizations at the state level. In addition to a description of the systems, the report contains information and suggestions for implementing similar photovoltaic projects.

INTRODUCTION

Sandia was aware that the most successful promoters of the technology are champions who understand its benefits and are able to communicate those benefits to others . . .

Photovoltaic systems have proven themselves to be reliable and cost-effective in providing electricity for a variety of needs, from smaller loads far from the existing utility grid to rooftop systems that at times feed into the grid. Yet many individuals and organizations are not familiar with renewable energy systems, and specifically with photovoltaic systems. This report offers information about the design, specification, purchase, installation, operation, and/or maintenance of photovoltaic systems so that readers can gain at least some familiarity with them. It provides not only descriptions of how photovoltaic systems are being used, but also something of the background behind their procurement and installation.

Photovoltaic systems have these unique and positive characteristics:

- Based on the widespread availability of sunlight, photovoltaic systems can be used in almost any non-shaded location
- There are no fuel requirements or combustion by-products
- Photovoltaic systems have relatively low operation and maintenance costs
- Modular in nature, systems can be easily sized to meet requirements
- Installation can be quick, and systems can even be made portable
- These systems can be sited at or very close to the load
- Photovoltaic systems are quiet and environmentally benign.

Two types of photovoltaic systems exist: those tied into the electricity grid (grid-connected) and those that power a system directly (stand-alone or remote-power). Grid-connected photovoltaic systems can generate electricity near the load, even on rooftops, and they can be used to reduce purchased electricity by serving loads or even contributing to the grid.

(Photo courtesy *Inside Tucson Business*/Scott Weisman)

Stand-alone systems, generally used in remote areas, reduce the need for fuel delivery, operate unattended (though they do require periodic maintenance, just like any other kind of system), and are often less expensive than obtaining grid power in a remote location on the basis of initial cost.

Some of the projects described here resulted from an agreement between Sandia's Photovoltaic Systems Assistance Center and the National Photovoltaics for Utilities Program (PV4U) to assist in fielding photovoltaic systems. The collaboration began in 1994, when contracts were placed to foster photovoltaic projects that would provide experience for members of PV4U throughout the United States. In 1996, in cooperation with the Interstate Renewable Energy Council, another round of projects was started to provide experience for its members and to assist agencies, utilities, and other organizations in obtaining introductory experience with solar electricity. Also included here are some additional projects that resulted from Sandia's direct association with state agencies.

Sandia's interest was to promote the use of photovoltaics by organizations that could very likely benefit from using this type of solar energy system. From past experience with such systems, Sandia was aware that the most successful promoters of the technology are champions who understand its benefits and are able to communicate those benefits to others in the organization. For this reason, considerable effort was made in promoting the use of photovoltaics to key staff in organizations so that when projects were implemented, a champion or champions would be interested in their successful outcome.

The bulk of the information about these systems was contributed by users and came from systems that led to other installations, from systems that had problems (two were stolen), and from systems very recently installed. The project summaries provide information on the installations, but some also indicate when additional photovoltaic installations followed. Contact information is also provided for those wishing more information about specific systems. Drawn from the information received, a list of suggestions for success was compiled that pertains to most photovoltaic projects. This list is presented first, and summary reports from the various states follow arranged in alphabetical order by state. A checklist follows the summaries, designed to help plan successful photovoltaic projects.

Suggestions for Success Based on Lessons Learned

State energy offices, state agencies, and other organizations have initiated and supported numerous projects using photovoltaic systems, and Sandia National Laboratories has had a part in many of them. The role for Sandia has been in assisting with a variety of services including providing basic information and technical assistance, reviewing bid documents and proposals, supporting installations, and monitoring system performance. The following discussions are presented in the hope that those considering such projects will be able to learn from the experiences of others in implementing similar projects. These projects demonstrate typical applications for photovoltaic systems, and the experiences likewise can be considered representative.

IDENTIFY EXPECTATIONS CLEARLY

Photovoltaic systems have characteristics that are advantageous for remote power applications and for grid-connected uses. To ensure the success of a photovoltaic installation, the customer must be educated about the capabilities of the system before the project actually begins, so that expectations will be realistic. Considerations to evaluate in deciding whether photovoltaics would suit a given application are

- Can a photovoltaic system meet the electricity needs of the application?
- What are the operational limits to its use?
- How much will it cost to install it?
- How much will it cost to operate and maintain the system?

To help educate individuals and organizations about photovoltaic systems, Sandia has over time developed documents that address many of these issues, and readers are invited to access the information offered at our web site, www.sandia.gov/pv, where project summaries provide illustrations of various applications for photovoltaic systems. The site also has much other valuable information about photovoltaics. In the appendix to this report is a "Photovoltaic Project Checklist" identifying much of the information needed and many of the steps necessary as one implements projects.

To ensure the success of a photovoltaic installation, the customer must be educated about the capabilities of the system before the project actually begins, so that expectations will be realistic.

The advantage these systems present over others is often compelling, and familiarity with their strong points is a real advantage in making the case for photovoltaics.

Our experience has shown that if the expectations of the system owner are not met, even if the system works well, the system and the project may be considered a failure. (This is true for virtually any purchase and is certainly not specific to photovoltaics.) If the performance does not meet expectations, if the costs are significantly higher than anticipated, if the energy or operating savings are not realized, or if the ongoing operation and maintenance costs become problematic, then the success of the project as a whole may be in jeopardy. By not meeting expectations—some of which are often unspoken or undefined—the installation may hurt the chances of a photovoltaic system being considered in the future by the user or agency involved. For this reason, upfront planning with a system designer or vendor will definitely benefit everyone.

GAIN SUPPORT WITHIN AN AGENCY FOR USING PHOTOVOLTAICS

As for any new technology with which an agency or organization is unfamiliar, support must be won to consider a photovoltaic system to provide power instead of using something better known. The advantage these systems present over others is often compelling, and familiarity with their strong points is a real advantage in making the case for photovoltaics.

A primary goal in developing a successful project is to find at least one champion within the sponsoring organization. This champion must have the drive and determination to become personally involved in the success of the project. It is best when champions can be identified on different levels, so that there is interest both from a high level and from local field personnel in the project's success. In addition, because staff in agencies are subject to changes in assignment, it is helpful to find multiple champions in different parts of the organization to keep the momentum going for the project. Even if there are champions, it helps the success of the project a great deal if management recognizes the importance of the project by formally making it part of the champions' jobs.

To garner this type of support and win over a champion for the project, the benefits must be clearly stated. Then, the project champion(s) will not only be convinced that it is the right thing to do, but will also be able to inform others in the organization about the project's benefits, which must be shown to clearly outweigh any perceived risks. To allay any doubts, it is often helpful to provide some guarantees that the project will succeed, and this means that the champion must be familiar with the technology, with the costs and benefits of the installation, and with how it will be implemented.

DEFINE THE PROJECT REQUIREMENTS

The procuring organization can either work with a vendor to define requirements for the system or work on them alone if it has the skills to do so. The organization can also hire a firm to prepare the design specifications. Of course, in evaluating the qualifications of designers and vendors, standard business practices should be followed. Once a project has been envisioned, requirements, needs, and expectations must be put in writing so that a vendor can understand in detail what the customer wants. This written understanding is particularly important when a performance specification relies on the vendor to design and specify certain equipment to meet system requirements.

Some effort should be spent to determine how a photovoltaic system will fit into the organization's own business practices and to translate its operational expectations into certain understandings not only about how the system will operate, but who will maintain the system and how.

Many factors must be considered in siting a photovoltaic system because they will affect its performance, including trees that might shade the modules, snow loading, rainfall or lack of it, excessive heat or cold, or other adverse environments. The visual impact of the system is important too, because it affects overall satisfaction with the system. Not only does the solar resource vary from location to location, but so does the environment in which the system must operate. A system that works in one locality might not work as well in another. Having specifications prepared by a local designer or a system designed by local vendors ensures familiarity with local conditions important to the photovoltaic system. Even provisions for regular maintenance or maintenance related to the environment can also be designed into the system.

In addition, it is important to design to protect the investment in the system. Vandalism and theft are not restricted to photovoltaic systems, but are significant for them because the replacement cost of the equipment is high, and photovoltaic systems tend to attract attention. These problems also tend to surface when the installation is remote. Without personnel nearby to protect the systems, extra care must be taken to keep theft and vandalism from occurring. It may be important to employ various solutions. Protective metal shields can be placed on the back of photovoltaic modules to protect from rocks being thrown at the undersides of the modules, especially when the modules are mounted high off the ground, making the upper surface difficult to vandalize.

To mitigate problems with theft, specify theft-deterring mounting hardware that requires special tools to remove the photovoltaic modules and any other valuable items, such as the battery and control boxes. To the extent possible, the modules can be kept out of sight and out of reach. If the system is large, it may require a security fence around the installation. One option in areas that experience vandalism is to purchase unbreakable modules. This will not guarantee that vandalism will not cause them to fail, but it does require significantly more effort to damage them.

The visual impact is important too, because it affects overall satisfaction with the system.

ESTABLISH A SCHEDULE

A schedule should be established at the outset. Allowances must be made for the work of subcontractors, particularly if the system must be installed at a certain time of year, for example, before winter to avoid the consequences of bad weather.

Sandia's experience in working with large organizations, particularly state agencies, has shown that an agency is often affected by events outside its control, such as policy actions taken by state legislatures or by the impact of utility restructuring. Defining requirements, drawing up contracts, interacting

with other government agencies all takes time, and allowances should be made for doing each one. Development of a realistic schedule will minimize problems throughout the course of a project.

DETERMINE A BUDGET

High-quality design and installation are an important part of a system's cost-effectiveness, and a failed inexpensive photovoltaic system will never pay for itself, whereas a photovoltaic system that might cost somewhat more and works reliably can provide the expected benefits. First arrive at reasonable expectations, then make a realistic cost estimate for doing the project. In initially considering photovoltaics, an organization may be interested, but the costs must be known before fielding a project. Obviously, a quality budget estimate is needed. This should include the cost of the installed hardware, the ongoing costs of operations and maintenance, and the cost to develop and implement the project.

First arrive at reasonable expectations, then make a realistic cost estimate for doing the project.

When making a budget, contact with members of the photovoltaic industry is obviously very helpful, because a clear concept of what is actually needed to complete the project will aid in determining its cost. The danger in not preparing a realistic and detailed budget is—as in any project—that the actual bidded price for a system may exceed a rough estimate and thus jeopardize the project. In addition, downstream costs should be taken into account, as they should be with any system. For example, for a photovoltaic system, replacement batteries can be a significant cost later on. Battery storage has a significant impact on the cost and efficiency of these systems; over a twenty-year period, battery replacement will add $3.50 per watt to the system's present-value cost, and batteries decrease the system's efficiency by as much as 20 percent during charge and discharge. These observations assume three days of usable battery storage at 50 percent depth of discharge and a battery lifetime of seven years. Costs will be greater for shorter lifetimes.

SELECT A QUALIFIED VENDOR

An organization should take care to select business partners in accordance with its long-established procedures. The qualifications of contractors who will design and install the system are very important. The highest quality equipment is only as good as the installation practices used to install and wire the equipment; improper wiring will lead to premature system failure. At times this is due to improper or insufficient specifications, but these problems may also be due to inexperience of the electrical installer. Training of personnel and use of inspectors or staff is recommended. Definition of acceptance testing is often included in the task requirements. Several companies provide design and installation services on a national level, but this does not necessarily address ongoing maintenance.

Another possibility is to determine if the local electric utility company has any interest in providing electrical service using photovoltaic systems in remote areas. If that service is made available through the utility, the procurement process could be greatly streamlined.

MEET ONGOING MAINTENANCE REQUIREMENTS

The organization must pay attention to maintenance in its decision to use a photovoltaic system. Maintenance can be performed by an organization's own staff, or the service can be provided by a contractor. If the work is contracted, it is important that local maintenance personnel be well versed in the operation and maintenance of the equipment. If a contracted maintenance agreement is not provided, then it is imperative to have trained personnel capable of carrying out those tasks. Although photovoltaic systems can require very little maintenance, they will always need some type of periodic care. If care is neglected, failure will result. This is why it is so important that local personnel take a personal interest in the project. They will be vital to the project's ultimate success.

One way to help is to provide training for the maintenance staff and electricians who work in the areas where the systems are to be installed. The vendor often defines operations and maintenance requirements, and may be able to provide such training if it is included as part of the procurement requirements.

Reliability of stand-alone systems

Detailed maintenance and reliability data was collected in Colorado on small, grid-independent lighting systems that did not include an inverter; the data is summarized in the table below. These systems operate in the Colorado State parks. The data shows that vandalism accounted for 60 percent of the maintenance costs—without including that, initial reliability of these photovoltaic systems is excellent. The systems had 96 percent availability, a rate of better than 13-years mean time between failure, and a maintenance cost of $25 per system per year. Chris Dunne, the person in the Colorado State Energy Office who designed, installed, and maintained the systems, recommended designing a standard system with few components, one that is easy to maintain and replace. He developed a control board with only four components, and minimized field assembly by putting the control board in a weatherproof box so that after mounting it, he only needed to connect the panel and loads to it. He recommended a semi-annual check of each system.

	MAINTENANCE DATA	
	Counting Vandalism	Not Counting Vandalism
Initial Mean Time Between Failure	7.9 years	13.5 years
Initial Mean Time to Replace	63 days	66 days
Percent Available	94.6 percent	96.5 percent
Cost to Maintain	$58/system/year	$25/system/year

Reliability of photovoltaic systems in Colorado Parks project (monitored 1/97 to 7/97). Note: This did not yet include battery replacement, which is a periodic necessity that will add significantly to the cost of maintenance. (Table from A.B. Maish et al., “Photovoltaic System Reliability,” 26th IEEE Photovoltaic Specialists’ Conference, Sept. 1997, Anaheim, CA.)

Remember: Thousands of systems are working to meet the needs of agencies, organizations, and individuals, and the numbers of systems are growing every year.

ARIZONA

Tucson Electric wanted to put the system in a location with high visibility to bring the attention of the public to it.

The Tucson Electric Power Company installed a 5-kW grid-tied photovoltaic system at the University of Arizona's Agricultural Center. The goal of the project was to demonstrate the workability of and to identify any problems with a locally installed, grid-connected photovoltaic system that would be used to provide power primarily during periods of peak utility loading. Specifically the system was used to:

- Determine the load-matching capability of photovoltaics in Tucson
- Measure the demand-side impact of photovoltaics
- Calibrate commercially available photovoltaic design programs.

For Tucson Electric, grid-connected photovoltaics provides value in acting as a distributed-generation resource. Such a distributed source has the potential to reduce the fuel, transmission, and distribution costs that utilities pass on to their customers when they provide energy from remote generation.

The original plan specified a turnkey installation, but the proposals received exceeded the limited project budget. A second, hardware-only request was re-bid, and the award went to Applied Power Corporation (APC), Lacey, Washington. Tucson Electric provided the civil/structural engineering and labor. The total cost of the system was nearly $100,000, but much of the expenditure was due to the non-standard civil/structural work.

Tucson Electric Powers' photovoltaic system has statue-like artistry at the University of Arizona's Agricultural Center.

All electrical design was provided by APC. Twenty-four ASE Americas 300-W panels were assembled into four-panel subarrays on the ground and hoisted into place with a large forklift. The system came on-line with a system output of 4.2 kW, achieved at approximately 3 p.m. MST, on December 14, 1995.

Tucson Electric wanted to put the system in a location with high visibility to bring the attention of the public to it. This trial use of photovoltaics contributed to continued interest by the utility, which now has a commercial interest in Global Solar Energy.

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COLORADO

In 1997, five grid-connected residential systems were installed in northern Colorado by the Community Office for Resource Efficiency (CORE), a nonprofit organization whose mission is to promote resource efficiency and renewable energy. In a partnership unique across the country, two of CORE's primary sponsors were Holy Cross Electric Association and Aspen Municipal Electric. This teaming of utilities and an environmental organization was noteworthy.

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The primary goal of the project was to promote the use of grid-connected photovoltaic installations, and in addition, to monitor, evaluate, and, document the installation of this kind of system. The project was specifically designed to gain experience with photovoltaic systems in the context of a rural utility, pioneer the use of grid-connected photovoltaics in western Colorado, and stimulate the emerging residential market for grid-connected photovoltaics.

Photovoltaic system on residence in northern Colorado.

When installed, this system in Aspen was the largest grid-connected residential system in Colorado.

A campaign to publicize the project elicited 20 prospective users, and five agreed to purchase photovoltaic systems after discussions about price and performance. The resulting systems were

- A 1.8-kW pole-mounted system in Carbondale. The homeowner did some of the initial construction work, and it cost $12,500.
- A 4.5-kW installation on a flat roof in Aspen. This system cost about $35,000 and was at the time the largest grid-connected residential photovoltaic installation in Colorado. One of its unique design features is a structure that will extend the array above expected snow levels on the roof in winter.
- A 1.35-kW system in Eagle, which cost $11,500 installed.
- A 1.35-kW rooftop system in Glenwood Spring, which also cost about $11,500.
- An 800-W system in Basalt costing $5,000 (subsidized price).

Siemens modules were purchased from Hutton Communications in Denver, and other modules were purchased from the Solarex Corporation. Structures were provided by Direct Power and Water Corporation, and inverters were provided by Trace and Omnion. These systems have been registered as early participants in the United States Million Solar Roof Program. Holy Cross Electric Association agreed to net meter these systems; the meter spins backward at midday in times of surplus photovoltaic production. Holy Cross Electric Association now has more grid-connected residential photovoltaic systems in its service territory than any of the 930 rural electric utilities in the nation and now has the largest photovoltaic program of any rural electric co-operative in the country.

Residential photovoltaic system in northern Colorado.

One of its unique design features is a structure that will extend the array above expected snow levels on the roof in winter.

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HAWAII

Photovoltaics is especially viable as an energy option in Hawaii because of ample sunshine in many locations and the high cost of island economies

The Hawaii Electric Lighting Company (HELCO) completed two demonstration projects in 1995 to gain experience with photovoltaics within the framework of a utility. One was a mobile trailer to demonstrate how photovoltaics can be used. Furnished by Renewable Energy Services, it has four 64-W Solarex Modules and a Trace 4-kW inverter, and cost $15,000. This unit has been shown in all regions of Hawaii, and on Maui and Oahu. In doing the project, the utility established a working relationship with the existing photovoltaic industry and indirectly influenced the revision of Hawaii county regulatory policies, which had presented obstacles to homeowners who wanted a legally permitted system. The design, installation, and purchase of some of the equipment for the demonstration trailer was specified as a turnkey system.

The other was a remote residential-scale photovoltaic system at Ahalanui County Beach Park. For this system, HELCO acquired all load information and defined requirements to draw up a request for proposals for the design. Using the design, a second contract was established with electrician David Almer to provide all the equipment and its installation. This system had a combined design, procurement and installation cost of $37,200. The park is far from the utility grid, and this alternative power system alleviates concerns for providing electricity at the park. This system was installed with 1.5 kW of Siemens modules and also used a Trace 4-kW inverter.

Trailer used to display working components of a typical, remote home-photovoltaic system—public reaction to it has been postive.

Given that each of these projects has an educational role, there were expenses associated with the educational and display components for each project. The trailer, while being used at numerous public events, conferences, and workshops, has provided HELCO staff with an excellent means to interact positively with the general public. HELCO has used this introductory experience well, because since then it has become one of the leading utilities in the use of photovoltaics with many follow-on photovoltaic systems having been installed.

Photovoltaics is especially viable as an energy option in Hawaii because of ample sunshine in many locations and the high cost of island economies.

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Location of photovoltaic system at beach house offers opportunity to educate public about photovoltaics as well as to provide needed electricity.

MARYLAND

In May of 1994, the Maryland Energy Administration partnered with Southern Maryland Electric Cooperative, Inc. (SMECO) to field a photovoltaic project, which is described here.

SMECO used photovoltaic systems to provide lighting for three brick welcome signs at Leonardtown, the county seat for St. Mary's County. This particular project was chosen because the site is in a popular location and the project would have high visibility, and also because the use was determined to be cost-effective. This was also a simple electrical load with minimal variables, so the evaluation of the technology was simplified. The selected system was a ground-mounted power unit manufactured by Solar Outdoor Lighting (SOL). The cost of these systems averaged around $3,500.

This particular project was chosen because the site is in a popular location, the project would have high visibility, and because the use was determined to be cost-effective.

Each SOL system included a single vandal-resistant enclosure containing two solar panels, two batteries, a charger/controller, and a 39-W dc fluorescent light fixture. Installation time averaged three hours. The first site has been operational since November 1994; the second was completed in September 1995 and is located at the cooperative's local office; and the final site was completed in October 1995. Unfortunately, during the first night it was there, a tree fell onto the array. Several welds on the top of the enclosure were separated, but the system was soon repaired. All remain in operation. This project led to another, in which the Cooperative automated a remote switch on a 66,000-volt transmission line located in Calvert County. This switch was operated remotely via a radio communications link powered by photovoltaics. SMECO was so

Dave Johnson, SMECO, installing a meter on a photovoltaic system.

pleased with the projects, that it eventually dedicated a budget of $15,000 a year for more photovoltaic systems.

During the course of installing and using photovoltaic systems, the Cooperative determined that the main reason photovoltaic systems are not being used more is a lack of familiarity with them. For this reason, educational presentations to schools, businesses, the marine industry, environmental and historical organizations, and the general public were found to be the key to identifying potential markets, interest, and applications.

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"Combining our solar application with the Leonardtown signs seemed a perfect match," Tom Tudor, SMECO engineer.

MASSACHUSETTS

In Massachusetts, Ascension Technology, Inc., worked with five Massachusetts utilities to develop an ac photovoltaic-powered street light. In 1994 and 1995, Commonwealth Electric, Eastern Utilities, New England Electric, Northeast Utilities and Taunton Municipal each installed at least one streetlight powered by photovoltaics. These photovoltaic lighting systems were priced at less than $5,000.

It was also important to have a diagnostic procedure that could be easily understood, remembered, and used by linemen unfamiliar with the photovoltaic system.

A utility-grade solar-powered streetlight provides safety and reliability in remote areas beyond the utility grid.

The 563-W ASE Americas photovoltaic array that supplies power for the lights was designed to be lifted in pieces to the top of the pole and then bolted-down and wired together. Two separate skill sets were required: a lineman to hoist the equipment to the top of the poles, and an electrician to wire them, because the wiring is like household wiring, done by a licensed electrician, and not by a utility lineman. It proved to be quicker, and less expensive to pre-assemble the photovoltaic modules, controls and batteries and then to hoist the entire assembly to the top of the pole.

It was also important to have a diagnostic procedure that could be easily understood, remembered, and used by linemen unfamiliar with the photovoltaic system. The utility also learned that the individual components of this system were not optimized to work together and that an integrated inverter, charge controller, and light controller could do the job more efficiently. Ascension began a follow-up project with Sandia to address these issues and provide easier installation, better diagnostic tools, and an integrated electronics package.

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Pre-assembled photovoltaic modules, controls, and batteries are hoisted to the top of the streetlight's pole

MISSOURI

The Missouri Department of Conservation and the Department of Natural Resources have recently allocated millions of dollars to fund projects that would improve the quality of streams and rivers while providing a habitat for Missouri's fish and wildlife. One of the prime reasons for this water quality issue is that cattle drink from these streams, trample the shorelines, and leave waste in the water, causing soil erosion and other water-quality problems.

The conservation department provided technical and financial assistance to farmers and ranchers to pump water to cattle tanks away from the streams using photovoltaic pumping systems . . .

The conservation department provided technical and financial assistance to farmers and ranchers to pump water to cattle tanks away from the streams using photovoltaic pumping systems, thus providing an alternative to allowing livestock to water from streams. However, the department was concerned about the sustainability of the program, and in particular:

- The education of farmers and ranchers regarding the reliability of the photovoltaic pumping systems
- Technical oversight to ensure that quality photovoltaic systems were professionally installed at competitive prices
- Long-term maintenance of the systems once hardware was installed
- On-going marketing and promotion of the program to the agricultural community.

Photovoltaic system assembled in shop and ready to transport and install.

From these concerns came a series of workshops in 1997 facilitated by the Empire District Electric Company and supported by Sandia National Laboratories, on installation of photovoltaic water-pumping systems designed by the Photovoltaic Services Network (PSN). More than 100 people involved in agricultural and conservation organizations participated in these workshops to install five water-pumping installations. They were located regionally throughout the state at Springfield, West Plains, Cape Girardeau, Owensville, and Linneus. The size of the photovoltaic systems ranged from 100 to 200 W, and the cost was typically in the $2,000 range. Solec provided the modules, and the pumps were supplied by Solarjack. Photovoltaic Services Network provided the system integration.

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Hands-on workshop for installing photovoltaic water-pumping systems.

MONTANA

A 1994 Montana report showed that the Big Hole River and many of its tributaries were on a list of impaired or threatened water bodies, largely because of alterations of flow caused by demands for stock watering, irrigation, and public water supply. The alteration in flow had produced dewatering of natural drainages, increased water temperatures, and decreased dissolved oxygen. These problems are worst in the late summer, threaten the rivers' rainbow trout fisheries, and pose a hazard to the fluvial Arctic grayling, the last remaining population in the continental United States. Much of the water diverted for stock watering is distributed through unlined ditches and canals, and most of the water diverted is lost to evaporation, transpiration, and infiltration before ever reaching the livestock.

This situation led to projects to develop off-stream watering sites to replace the use of surface water distributed through unlined ditches. One of the eight projects used photovoltaics. A trailer-mounted, self-contained photovoltaic pumping system was installed in the Big Hole Valley of Southwestern Montana to provide stock watering and to help alleviate dewatering problems in the Big Hole River. The system consists of a 12-module (53 W

The system was sized to pump about 6,750 gallons per day from a depth of 40 feet during the months of August through October.

Photovoltaic system arrives on site.

each) array and an A.Y. McDonald submersible pump. Big Horn County Electric Co-Op was selected to provide and install the system. The system was sized to pump about 6,750 gallons per day from a depth of 40 feet during the months of August through October. Storage tanks to provide approximately 12,000 gallons of water were installed at the primary site. A gravity-feed piping system from the main storage tanks will allow the water to be distributed to watering areas in three different pastures. An $11,000 trailer-mounted system was selected so that it may be used at other sites when not in use at the original site and so that it may be stored under cover during the severe winters experienced in the area.

The project was a team effort, and local groups (the Big Hole Watershed Committee, the Beaverhead Conservation District, Vigilante Electric Co-Op), state government (Department of Environmental Quality, Department of Fish, Wildlife, and Parks), and Federal government (Natural Resources Conservation Service) all played important roles in its completion. The local groups worked with local ranchers to select the appropriate site and to obtain pumping requirements. They also worked with the Natural Resources Conservation Service on the design and installation of the storage system. The local electric co-op assisted in the installation of the system and will be working on any ongoing maintenance needs the system may require. The Montana Department of Fish, Wildlife, and Parks provided assistance with the well drilling costs and development of the storage system. The Department of Environmental Quality provided assistance during the design and procurement of the pumping system. The system was procured by the Beaverhead Conservation District with the assistance from the Department of Environmental Quality. The fact that all these different groups could work together and complete the project speaks to the value of the project to everyone involved.

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Trailer-mounted photovoltaic system installed by Rodney Rogers, Bighorn Electric Co-Op, Rod Sining, Vigilante Electric Co-Op, and Clay White, Department of Environmental Quality.

NAVAJO NATION

The people who will benefit most are the most traditional members of the Nation, who reside in isolated areas and prefer to remain there.

In 1994, the Navajo Tribal Utility Authority (NTUA) began a residential solar energy program on the Navajo Nation as a way to provide electricity to remote areas without having to use expensive line extensions. An estimated 180,000 Navajo live in isolated extended-family dwelling units scattered over the 26,000 square miles served by the utility, and the solar systems provide electricity and at the same time allow the families to continue their traditional Navajo way of life.

In looking into how to provide electricity for remote areas of the Nation and then considering photovoltaic systems to supply some of the need, the NTUA was encouraged by the Navajo Nation Council to pursue solar power. The people who will benefit most from its use are the most traditional members of the Nation, who reside in isolated areas and prefer to remain there.

The NTUA chose small photovoltaic systems capable of producing about one kilowatt of power per day on a sunny day, with batteries that provide four to five hours of electricity at night—not a great deal of power, but more than most families had before the systems were installed. The photovoltaic systems and battery storage power several lights and small appliances. NTUA owns and maintains the systems, and homeowners monitor the systems and ensure the batteries maintain their charge.

Three types of packaged systems from several vendors were used:

- Solar Engineering Services (now Applied Power Corporation) of Lacey, WA, provided a Mobil solar module, a one-piece unit with a 260-watt photovoltaic array and a white, low-profile enclosure with two compartments, one holding the controls and battery charger/inverter, the other containing a maintenance-free battery bank.

Sandia demonstration trailer promotes NTUA solar electric home systems.

Petersen Zah (former president of the Navajo Nation) and Navajo Tribal Utility Authority staff at dedication of first NTUA system installed on the home of Rose Wilson.

- Photocomm (now Golden Genesis) of Scottsdale, AZ, provided a system with four Solarex modules in a 224-watt photovoltaic array and a white metal, narrow-profile enclosure with two compartments, one on top of the other. The top compartment holds the controls and battery charger/ inverter, and the lower one contains the maintenance-free battery bank.

- SunMart of St. Michaels, Arizona, provided a system consisting of four Siemens modules in a 200-watt array, with a white cabinet containing the batteries, inverters, and controls.

More than seventy systems were initially installed in what was a joint effort involving the Navajo Tribal Utility Authority, the Department of Energy, Western Power Administration, and Sandia National Laboratories. The NTUA has continued this program, and another 100 systems of a later design are now on order.

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In looking into how to provide electricity for remote areas of the Nation and then considering photovoltaic systems to supply some of the need, the NTUA was encouraged by the Navajo Nation Council to pursue solar power.

NEW MEXICO

In 1998, Albuquerque's Rio Grande Nature Center (RGNC) installed three solar-powered aeration systems in its main pond at a total cost of $11,000. Each part of the system consists of a two-panel BP Solar collector, a marine storage battery, and a control box. In the pond are three underwater aerators connected to the system by PVC pipe.

This project had been under consideration for several years as one possible solution to the oxygen problem in the pond. Aeration is preferable to chemical control of algae growth, which has a detrimental effect on some organisms and tends to eliminate algae rather than reduce it. Although aeration systems, in and of themselves, are not costly, the electrical provisions of service are. When the Center constructed an additional pond in 1994, the decision was made to feed water to the pond from a well powered by the sun. The project was a great success, and it was soon discovered that the new pond was healthier and had considerably more aquatic life than the old one. In 1995, the RGNC dredged the old pond at a cost of nearly $7,000. After the dredging, the Center decided to pursue a less costly, long-term solution to the oxygen problem, one involving solar collection and operation.

The project was a great success, and it was soon discovered that the new pond was healthier and had considerably more aquatic life than the old one.

The photovoltaic-powered aeration systems were installed to stabilize oxygen levels in the pond in summer to sustain aquatic life, prevent disease, and control algae growth. In winter, the aerators serve as de-icers. Uncontrolled algae growth contributes to the fall in oxygen

A photovoltaic system powers the aeration system at the Rio Grande Nature Center.

levels at night, resulting in the death of some organisms. In winter, the ponds provide some of the only open water along the Rio Grande for migrating waterfowl, providing safe resting areas and food. Water-quality testing is conducted once a month. Oxygen levels have increased significantly since installation of the photovoltaic aeration system.

This project was a joint venture with Sandia National Laboratories, New Mexico State Parks Division, and the Energy, Minerals and Natural Resources Department Energy Conservation program. The project was bid competitively and awarded to Keaton Industries in Fort Collins, Colorado. Installation was completed by the Nature Center staff and volunteers.

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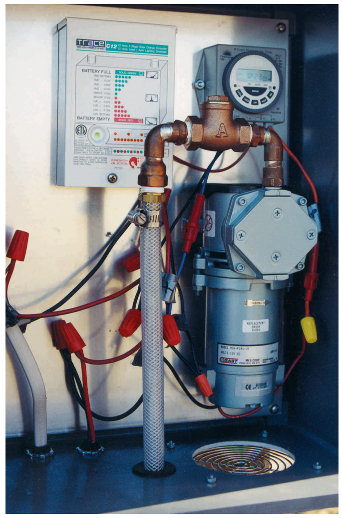

Battery bank and controls.

Aerator in pond.

NEVADA

The Nevada Energy Bureau/Governor's Office of Community Services held an educational workshop in Las Vegas in May1993 about energy systems, and during the workshop, Nevada Test Site personnel (presently with Bechtel Nevada) obtained information that led to using photovoltaics. They decided to use photovoltaics to provide electrical power for air samplers in remote areas on and near the Nevada Test Site where commercial power is not available and is too expensive to bring in.

They decided to use photovoltaics to provide electrical power for air samplers in remote areas on and near the Nevada Test Site where commercial power is not available and is too expensive to bring in.

The air sampling is conducted to asses the concentrations of radioactivity in airborne particles and atmospheric moisture to assure that the air is in compliance with Federal regulations. Before using photovoltaics, use of these air samplers was restricted to locations where commercial power was available, which sometimes resulted in less than optimal placement with regard to past nuclear weapons testing, local topography, and meteorology. The particulate air sampler requires continuous power, with a peak of 700 watts ac. The atmospheric moisture sampler for detecting airborne tritiated moisture requires continuous power, with a peak of only 10 watts ac.

Sandia helped the Test Site staff define the system requirements and prepare a purchase specification for nine air quality monitoring systems powered by photovoltaics, which were installed during 1995. Two slightly different designs were purchased for the particulate air samplers at different times. The photos show both of the designs. At the present time, twelve

Air-quality monitoring system at Nevada Test Site.

systems (ten airborne particulate sampling systems and two atmospheric moisture sampling systems) have been purchased through multiple orders at a total cost of $480,000. Applied Power Corporation provided the first systems, and Photocomm (now Golden Genesis) provided later systems.

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Smaller system for atmospheric moisture sampling.

A 3.4-kW photovoltaic system installed on five skids at Nevada Test Site powers an air sampler.

NEW YORK

The Bennington Battlefield Photovoltaic Project was begun in 1994 to provide electricity for water pumping and lighting for a comfort station at a remote historic site that is owned, operated, and maintained by the New York State Department of Parks, Recreation, and Historic Preservation. The site was identified as a good candidate for photovoltaic-generated power in a 1993 study for the New York State Energy Office conducted by the SAIC/The Fleming Group and AWS Scientific.

Installation was scheduled for the summer of 1995, however the project was delayed when the New York State Energy Office was dissolved in early 1995. The New York State Energy Research and Development Authority assumed the responsibilities of the former state office, and it restarted the project in the fall of 1995.

The enthusiasm of a project engineer may have been responsible for the agency's general acceptance of photovoltaics for this application, and, in addition, photovoltaics proved to be the low-cost solution to the agency's power needs.

The system's appearance was a major concern of the New York state agency, and the challenge for designers was to locate the system so that it would have good solar access, but would not be a visual distraction to visitors. After a few iterations, a suitable location was found for a pole-mounted array. It might be noted that appearance is a particularly sensitive issue for parks no matter where they are found, and it is important that if a photovoltaic system is used, it be unobtrusive and not distract from the natural beauty or historical surroundings.

A 550-W system using Siemens modules, Trojan deep-cycle batteries, and Trace inverters was installed in 1997 by ABCO Multi-Trades Corporation to provide water pumping and lighting, the prime electric loads at the site. The parks department at Bennington estimated that the average daily water usage of the comfort station (after the installation of water-conserving

The photovoltaic system beside the Bennington Battlefield comfort station.

toilets) is 180 gallons per day, and the lighting requirements are minimal (less than 300 watthours per day). A 310-foot well had been drilled in 1995 to serve as the water supply, and the existing 1000-gallon concrete storage tank was used with a small booster pump to supply water to the comfort station. The $11,000 photovoltaic system also powers three compact fluorescent lights (on timers) to illuminate the restrooms and a small utility room in the comfort station.

The enthusiasm of a project engineer may have been responsible for the agency's general acceptance of photovoltaics for this application, and, in addition, photovoltaics proved to be the low-cost solution to the agency's power needs. The photovoltaic system was shown to be 19% lower in levelized cost than a line extension from the grid. The comfort station is not unique in design or load; it is similar to other facilities located throughout the state, including the more than 150 parks, campgrounds and boat launch facilities under the New York Parks system. Unfortunately, the major components of the system were stolen in 1998; however, the participants in the project will replace the system and will include measures to avoid a repeat occurrence of theft.

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An all-too-accessible photovoltaic system . . . it was stolen.

OREGON

Two photovoltaic water-pumping systems were installed in Oregon in 1998 to help improve conditions in a riparian zone. The improvement that the state energy office wanted to make was to plant buffer forests along rivers that would remove nitrates and phosphates from field lechate, which was getting into the water. In comparing photovoltaics and grid-extension to provide power for water pumps, the photovoltaic systems proved to cost less than line extension. The solar systems were also chosen to provide the state with small-scale applications for photovoltaics and to give impetus to establishing a library and other resources on photovoltaic applications.

In comparing photovoltaics and grid-extension to provide power for water pumps, the photovoltaic systems cost less than line extension.

The Oregon Office of Energy worked in partnership with the Oregon State Agriculture Extension Service to locate sites for the systems. One example is the Tromp Von Holst ranch site, where an irrigation system was designed for a plot of marginal agricultural land that had been used for raising winter cattle feed or other crops. The forest that was planted is about 1 mile in length and includes 500 to 600 hybrid poplar seedlings known for their phosphate and nitrate uptake as well as root systems that prevent erosion. Four Solec panels capable of producing 60 W each power a Solarjack submersible pump, and a controller is included in the system. The water is pumped to a central holding tank where it is distributed to a feeder line and to a drip branch. It also waters cattle to keep them away from the fragile riparian zone. The pilot project was implemented through the Agricultural Service agency, the Oregon Office of Energy, and the landowners. The systems were installed by the owners and the local Agriculture Service agent. The cost was around $4,000.

Another system, intended to water livestock at Hotchkiss Farms, was designed with a Siemens solar array, consisting of two panels each capable of producing 80 W, a Solarjack pump,

Water-pumping systems help improve conditions in a riparian zone.

and controller, with a maximum pumping rate of 3.5 gallons per minute. This system cost $4,500. A 4,000-gallon concrete trough was also installed along with 25 feet of pipe.

The Oregon business energy tax credit provides 35% credits to any Oregon rancher or farmer interested in installing this technology. The small-scale energy loan program will provide an incentive through fixed rate loans with 10- to 15-year terms.

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The Oregon business energy tax credit provides a 35% credit to any Oregon rancher or farmer interested in installing this technology.

Photovoltaic system at Hotchkiss Farms helps keep cattle away from fragile riparian zones.

UTAH

Several years of effort to replace diesel generation at the Dangling Rope Marina on the north shore of Lake Powell culminated with the installation of a photovoltaic array of a nominal 110-kW nameplate output, a battery system of 2.4 MWh, replacement of the existing diesel generators with two propane-fueled engine-generators, and a hybrid power converter that will condition the power to meet the needs of the site users. The system cost about $1,400,000.

From this project, the Glen Canyon National Recreation Area anticipated:

- Engine generator run times of less than 1,450 hours per year. Shorter run times mean less noise and lower levels of pollution.
- Elimination of the risk of a diesel fuel spill on Lake Powell.

The Glen Canyon National Recreation Area had generated electricity for the Dangling Rope Marina at an average cost of $0.38/kWh. Diesel generators ran continuously and consumed 65,000 gallons of diesel fuel each year to provide electricity to the marina. This required 40-mile barge trips up-lake and back 35 times per year. This round trip took 10 hours and cost the National Park Service over $1,000 a year. The generators created significant air and noise pollution at the Dangling Rope Marina site and exposed Glen Canyon National Recreational Area to the risk of a diesel fuel spill on Lake Powell.

Because this was such a large project, it involved a large number of partners, including the National Park Service, Utah Department of Natural Resources, Pacificorp, and Utah Power and Light, the Department of Energy,

Diesel generators ran continuously and consumed 65,000 gallons of diesel fuel each year to provide electricity to the marina. This required 40-mile barge trips up-lake and back 35 times per year.

Photovoltaic system at Dangling Rope replaces noisy diesel generators whose sound used to echo off these cliffs.

including the Federal Energy Management Program and Sandia National Laboratories, ARAMARK Leisure Services, and the Environmental Protection Agency. The installation was awarded in the fall of 1995 to Applied Power Corporation. On-site construction began in the spring of 1996, with photovoltaic modules supplied by ASE Americas, a hybrid power converter constructed by Kenetech Windpower, and battery storage system supplied by C&D Power Systems. In 1998, an additional 45 kW of array was installed to help meet the growing loads at the Marina.

One unique feature of this project is the market entry of a new product from a power processing manufacturer. The Kenetech (now Trace Technologies) hybrid power converter is the first photovoltaic/battery/engine generator power converter this company has made and reflects one of the reasons that Sandia and the photovoltaic program of DOE were participants in the Dangling Rope Project; that is, in developing hybrid power processing equipment to better utilize photovoltaic energy.

A detailed examination of the system performance is provided in Sandia's Photovoltaic Quarterly Highlights (volume 1, 1998) and can be seen at the Sandia web site: www.sandia.gov/pv/hot.htm.

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Dangling Rope system, on a hill away from marina.

Small photovoltaic system powers an informational sign.

VERMONT

Through the spring of 1997, twenty-eight solar panels generated power for an electric vehicle project on state property in Middlesex. Installed by Solar Works, the 2.1-kW Solarex photovoltaic array and Omnion 2-kW utility-interconnected inverter had been continuously on-line since June of 1994 without any outages or operational problems. Kilowatt and kilowatt-hour data were monitored by the Washington Electric Cooperative (WEC) through an on-site datalogger and modem. This was a noteworthy project because it was installed at a location where electric vehicle demonstrations for the State of Vermont were located. In fact, this $28,000-system operated quite well with few problems.

During the summer of 1995, the glass cover of one module was broken. It is suspected that this was caused by a rock thrown from a lawn mower. Periodic inspections noted, however, the important role of dust from the adjacent roadway, which led to accumulated dust on the modules that decreased output. At one inspection, technicians observed a significant 20 percent increase in output after cleaning the glass covers.

However there was subsequently a worse problem than rocks or dust; theft. Ironically, all twenty-eight solar panels were stolen on Earth Day of 1997, only yards from the Vermont State Police barracks, almost certainly to be installed and used by someone familiar with photovoltaic technology.

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This was a noteworthy project because it was installed at a location where electric vehicle demonstrations for the State of Vermont were located.

Kiosk explains how the grid-interactive photovoltaic system works.

WASHINGTON

In Washington, state energy officials developed educational materials and conducted outreach activities to build general awareness and to promote interest in installing photovoltaic systems for suitable applications. A portable display about photovoltaics was constructed using off-the-shelf, full-sized photovoltaic components integrated to create a fully functional demonstration system, which included photovoltaic modules/array, charge controller, control panel, storage batteries, inverter, and various ac and dc loads representative of a wide range of applications. Sandia provided technical assistance in building the display and helped run an early workshop.

With this as a focus, energy officials began an educational program, which included hands-on workshops, training courses, school classroom presentations, utility programs, and community fairs and events. Handouts and publications were distributed at these events. The modular nature of the display allows staff to use only a portion of the components to demonstrate a remote ‘direct-drive’ water pumping module with sprayer and water containment, and a stand-alone remote lighting module. Thousands of Washington residents were able to see off-the-shelf photovoltaic components producing electricity and powering conventional devices such as water pumps, televisions, VCRs, computers and lights.

When the energy office was closed in 1996, the energy education programs were transferred to Washington State University, Cooperative Extension Energy Program, which continues to educate and promote the use of photovoltaics.

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A portable display about photovoltaics was constructed using off-the-shelf, full-sized photovoltaic components integrated to create a fully functional demonstration system.

Portable system demonstrates operation of photovoltaics to classrooms and communities.

WISCONSIN

The Department of Natural Resources in Wisconsin promoted use of photovoltaic systems through a conference, and following it, individual property managers identified opportunities to use the systems at their locations. Site visits were made to evaluate some of the most promising, and estimates allowed a cost range for each system to be calculated. After the target projects were selected, the department issued requests for proposals, requiring that all be submitted as a lump sum amount including all equipment, installation, shipping, documentation, and warranty. All the proposals came in higher than estimated, largely because of a need for support structures. Although the original criterion for cost effectiveness was in comparison to the cost of line extension, the high cost of the proposals precipitated an evaluation of project priorities. Upper spending limits were established, load requirements were reduced by utilizing light-emitting diode (LED) lights, and negotiations were undertaken with selected contractors. For some projects, less expensive packaged photovoltaic systems were purchased. Since Department of Natural Resources maintenance personnel took an interest in photovoltaic systems, they performed the packaged system installations to further reduce costs. Some of the systems that resulted are presented here.

Since Department of Natural Resources maintenance personnel took an interest in photovoltaic systems, they performed the packaged system installations to further reduce costs.

At the Kettle Moraine State Forest's Southern Unit, two photovoltaic lighting systems were installed in restrooms at the Pine Woods Group Camp. The systems feature outdoor amber LED lights and interior compact fluorescent lights with occupancy sensors. The lights activate only under reduced daylighting levels. A photovoltaic lighting system was also

Photovoltaic system and lighted sign at entrance to Kettle Moraine State Forest.

installed on the entrance sign to the forest headquarters, which features low-pressure sodium lights that operate from about dusk to dawn. At the Turtle Flambeau Scenic Waters Area, a restroom photovoltaic lighting system similar to those at Kettle Moraine State Forest was installed. It has exterior amber LED lights, interior white LED lights, and a fluorescent light in a storeroom.

Advanced Composting Systems, Inc., of Montana assembled and installed these systems, which feature BP Solar photovoltaic modules, Trace C-12 charge controllers, Johnson Controls VRLA deep-cycle batteries, custom module brackets, custom light fixtures, and custom battery/equipment enclosures. The cost of each restroom lighting system ranged from $5,500 to $6,000, and the cost of the sign lighting system was $7,500.

Other installations at Kettle Moraine include a photovoltaic submersible water pumping system for a wheelchair accessible drinking fountain (Whitewater Beach) and a photovoltaic lighting/ventilation system (Pine Woods Campground, Loop 2). Currin Corporation (Midland, Michigan) supplied these as packaged systems, and they were installed by DNR maintenance personnel. The cost of the water pumping system was $3,180. The cost of the lighting/ventilation system was $3,120. The packaged system costs do not include installation.

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Restroom lights powered by photovoltaics.

PHOTOVOLTAIC PROJECT CHECKLIST

This checklist results from experience gained in fielding many projects. Discussion of all these items with a vendor may facilitate understanding the project's requirements. The list is provided to help think through a project involving photovoltaics. It is offered only as a guide; some of the items may only need to be considered initially, or can be assumed to be taken care of if circumstances warrant.

ITEM	NOTES
PROJECT DEFINITION	
Identify the need	
Characterize the electrical loads	
Estimate the solar resource	
Conceptualize the design	
Estimate the O&M needs	
Compare with alternatives	
Determine policy or other benefits that should be considered	
Is sufficient infrastructure available to support project?	
Are the expectations identified reasonable?	
Make and justify recommendation – is there buy-in?	
BUDGET PREPARATION	
Estimate initial costs	
Estimate O&M costs	

ITEM	NOTES
Estimate decommissioning costs	
Estimate lifetime costs	
Are sufficient funds available?	
PROJECT IMPLEMENTATION	
Assemble project team and assess its capabilities	
Has a project champion been identified, and are the assignments clear?	
Refine the functional description of the project and its goals	
Determine approach (i.e., vendor supplied)	
Will the user's needs be met with this approach?	
Identify site or operating constraints on design (i.e., maintenance, weather, autonomy of operation, etc.)	
Define land or roof area needs	
Determine any schedule constraints for the project	
Determine inspection requirements	
Define all requirements in procurement or other document	

ITEM	NOTES
Does the design use standard components?	
Obtain predicted reliability of system/ components and method of repair	
PROJECT DEPLOYMENT	
Define acceptance testing requirements	
Review vendor's schedule and submittals (i.e., construction/installation plan)	
Obtain as-builts and other turnover documents (i.e., O&M manual, spare parts list, etc.)	
O&M REQUIREMENTS	
Who has ownership and maintenance responsibilities?	
Define interfaces with partners	
Obtain design documents necessary for O&M	
Identify preventative maintenance procedures (and resources and schedules)	
Have safety issues been adequately addressed?	
Are there funds for periodic battery replacements if used in the system?	